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Preface

In the face of mounting global challenges posed by climate change, there exists an imperative to reshape the energy landscape, forging a path toward a more sustainable and resilient future. The following compilation of seven research contributions serves as a comprehensive exploration of this critical journey, illuminating the multifaceted facets of evolving energy systems and strategies. As we venture into the heart of this collection, we embark on a voyage through time, beginning in the late 18th century and culminating in the present day. This journey takes us through the annals of history, where we reflect on the progression of global warming from its inception in the 1800s to the present day. Along the way, a spotlight shines on the pivotal role played by Transmission System Operators (TSOs) and Distribution System Operators (DSOs) in shaping the energy landscape. The overarching theme of these works revolves around the C+++ Framework, a new concept that underscores the importance of coordination, cooperation, and collaboration between TSOs and DSOs. This framework represents collective efforts to integrate renewable energy technologies, power electronic systems, efficient energy demand management, and energy storage systems into existing energy infrastructure.

The first paper sets the stage by providing a historical backdrop, underscoring the significance of international agreements such as the Paris Agreement and their role in reducing greenhouse gas emissions. It is within this context that we delve into the C+++ Framework, recognizing its potential to guide sustainable energy endeavours. Subsequent contributions navigate intricate technical terrain, addressing the challenges posed by the intermittent nature of renewable energies, particularly wind power. They introduce real-time optimal power flow (RT-OPF) frameworks and explore the complexities of mixed-integer nonlinear programming problems. These articles propose innovative solutions that use battery storage systems (BSSs) and active-reactive optimal power flow (A-R-OPF) models to optimize the operation of energy distribution networks in the presence of constantly changing wind energy conditions. By doing so, they lay the foundation for more efficient and reliable energy systems in the face of renewable energy integration. As we explore this collection of research, it becomes evident that the journey to a sustainable energy future is marked by both promise and complexity. The integration of renewable energy sources, the management of energy demand, and the optimization of energy storage are all central themes that must be addressed collectively to ensure energy systems are resilient, sustainable, and capable of mitigating the effects of climate change.

This compilation represents a valuable contribution to the ongoing discourse on energy optimization, offering fresh perspectives, critical reviews, and innovative approaches to address the challenges that lie ahead. It is the hope that these contributions will serve as a valuable resource for policymakers, researchers, and industry professionals alike, as they navigate the complex terrain of energy transformation in pursuit of a reliable, efficient, and sustainable energy delivery system. With this, the journey begins, as exploration into the intricacies of energy optimization and the promise of the C+++ Framework. Through collaboration and innovative solutions, the objective is to pave the way for a brighter, more sustainable, and resilient future for future generations.

Aouss Gabash

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Review

Energy Market Transition and Climate Change: A Review of TSOs-DSOs C+++ Framework from 1800 to Present

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Abstract: In response to the pressing global challenges around climate change and the imperative of transitioning the energy market towards sustainability, this paper presents a comprehensive review starting from the late 18th century. The study examines the pivotal role of Transmission System Operators (TSOs) and Distribution System Operators (DSOs) in shaping the evolving energy landscape, with a specific emphasis on the C+++ Framework. This framework emphasizes coordination, cooperation, and collaboration between TSOs and DSOs to achieve sustainable energy systems through the integration of renewable energy technologies, storage systems, and efficient energy demand management. In addition, the review provides a historical overview of global warming from 1800 to the present, highlighting key events and developments related to greenhouse gas emissions. Furthermore, the paper delves into the significance of international agreements such as the Paris Agreement and the importance of reducing greenhouse gas emissions for a sustainable future. Recognizing the vital role of the C+++ Framework, the paper concludes with a discussion of future hybrid sustainable technologies incorporating various storage and efficient lighting technologies that can optimize energy management and reduce carbon emissions. This research aims to contribute valuable insights to inform energy policy and decision-making processes for a reliable, efficient, and sustainable energy delivery system.

Keywords: bidirectional A-R-OPF; climate change; C+++ Framework; energy market transition; flexibility; global emissions; power system operators

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1. Introduction

The urgency of building a sustainable future and establishing a global sustainable energy system highlights the critical importance of fostering strong collaboration between transmission system operators (TSOs) and distribution system operators (DSOs) [1–6]. TSOs and DSOs working together are vital for effectively managing and integrating renewable energy sources and storage systems, ensuring grid stability, and meeting the energy demands of a rapidly evolving world. Recent studies [7] have demonstrated the potential of incorporating storage systems such as battery storage systems (BSSs) [8] and considering their role in conjunction with TSO-DSO coordination models [9]. This can lead to effective leveraging of distributed energy resources, enhanced grid stability, and optimal utilization of sustainable resources.

To address these challenges, this paper introduces the C+++ Framework, which emphasizes the key elements of coordination, cooperation, and collaboration between TSOs and DSOs within the energy sector. Each "C+" symbolizes one of these essential elements, serving as a guiding principle for optimizing energy management in sustainable energy systems. The framework facilitates the seamless integration of renewable energy technologies such as wind stations (WSs) [10], solar photovoltaic (PV) sources [11,12], and efficient storage systems [13]. Section 3 intricately delves into the inception of the C+++ framework, which facilitates collaborative agreements between TSOs and DSOs. This is preceded by a concise overview of the historical evolution of the global sustainable energy system.

In this context, a sustainable energy system is defined as a comprehensive approach that meets current dynamic energy needs while simultaneously minimizing detrimental environmental effects and safeguarding resources for future generations. A crucial goal of such a system is to minimize global greenhouse gas emissions [14], measured in Gigatons (Gt) of carbon dioxide (CO_2) equivalent (CO_2e) [15,16]. Lowering CO_2e is essential for addressing climate change and reducing the impact of human activities on the environment [17]. Note that greenhouse gases are essential for maintaining a habitable planet by trapping heat and supporting life as part of the natural greenhouse effect. However, human activities have led to an enhanced greenhouse effect, causing anthropogenic global warming [18] and climate change, making it crucial to reduce greenhouse gas emissions for a sustainable future.

Because global warming is a complex and ongoing process that is shaped by various natural and human-induced (or anthropogenic) factors, a brief overview of significant events and developments related to global warming from 1800 to the present is provided below:

- Industrial Revolution (Late 18th to 19th Century). Between 1739 and 1792, numerous experiments on inflammable air were purely for philosophical curiosity, yielding no practical results [19]. These were used in the past to describe gases such as hydrogen [20], which can readily ignite and burn in the presence of oxygen. In the late 18th century, Murdoch pioneered gas illumination, starting with his house and office in Redruth, Cornwall in 1792, and continued his significant contributions to gas lighting technology by erecting a gas production apparatus at the Boulton and Watt manufactory at Soho in 1798 [19,21]. The industrial revolution marked a significant turning point in human history, with the widespread use of coal and later oil as primary sources of energy. This led to a substantial increase in greenhouse gas emissions, particularly CO_2, as factories, transportation, and other industries burned fossil fuels at an unprecedented rate.
- 19th Century. During the 19th century, global average temperatures began to rise gradually as a result of increasing greenhouse gas emissions. The widespread adoption of fossil fuels for electricity, transportation, and other industrial processes continued to drive the trend. Over the past two centuries, the United States (US) economy evolved from a rural nation into an industrial powerhouse, surpassing the United Kingdom (UK) as the global technology leader and becoming the world's wealthiest nation by the early 20th century, while the "Second Industrial Revolution" witnessed a substantial influx of European immigrants, driving the country's economic growth [22].
- 20th Century. Early 20th century: the warming trend persisted, driven by rapid industrialization and urbanization, leading to increased greenhouse gas emissions. Mid-20th century: a slight cooling trend was attributed to industrial aerosols and pollution blocking sunlight, though not enough to counteract long-term warming. Late 20th century: a significant acceleration in global warming has been fuelled by the continued rise in greenhouse gas emissions from human activities such as fossil fuel burning and deforestation.
- Intergovernmental Panel on Climate Change (IPCC) [23]. In 1988, the United Nations (UN) established the IPCC to assess scientific research on climate change. The IPCC plays a crucial role in providing regular reports and scientific assessments of climate change, including the impacts of global warming.
- UN Framework Convention on Climate Change (UNFCCC) (1992) [24]. The UNFCCC is an international treaty adopted in 1992. It came into force on 21 March 1994. Its main objective is to address climate change and its global impacts.
- Kyoto Protocol (1997) [24]. The Kyoto Protocol was adopted in 1997, aiming to curb greenhouse gas emissions and mitigate global warming. The treaty established binding emission reduction targets for developed countries. However, some major emitters, such as the US, did not ratify the protocol, limiting its global impact.

- Paris Agreement (2015) [25]. In 2015, the Paris Agreement was adopted, aiming to limit global warming to well below 2 degrees Celsius (°C) above pre-industrial levels, with efforts to limit it to 1.5 °C. This landmark agreement brought together nearly all countries in the world to commit to reducing greenhouse gas emissions and enhance climate resilience.
- Ongoing Trends. Global temperatures have continued to rise in the 21st century, with some years being the hottest on record (23 July 2023), as shown in Figure 1a [26]. The global mean surface air temperature for this period is approximately 14 °C. In addition, Figure 1b [27] shows temperature anomalies for the period of 1980–2015 in °C based on GISTEMP dataset from the NASA Goddard Institute for Space Studies (GISS). There have been more frequent and severe extreme weather events, such as heatwaves, hurricanes, floods, and droughts, linked to the impacts of global warming [28].

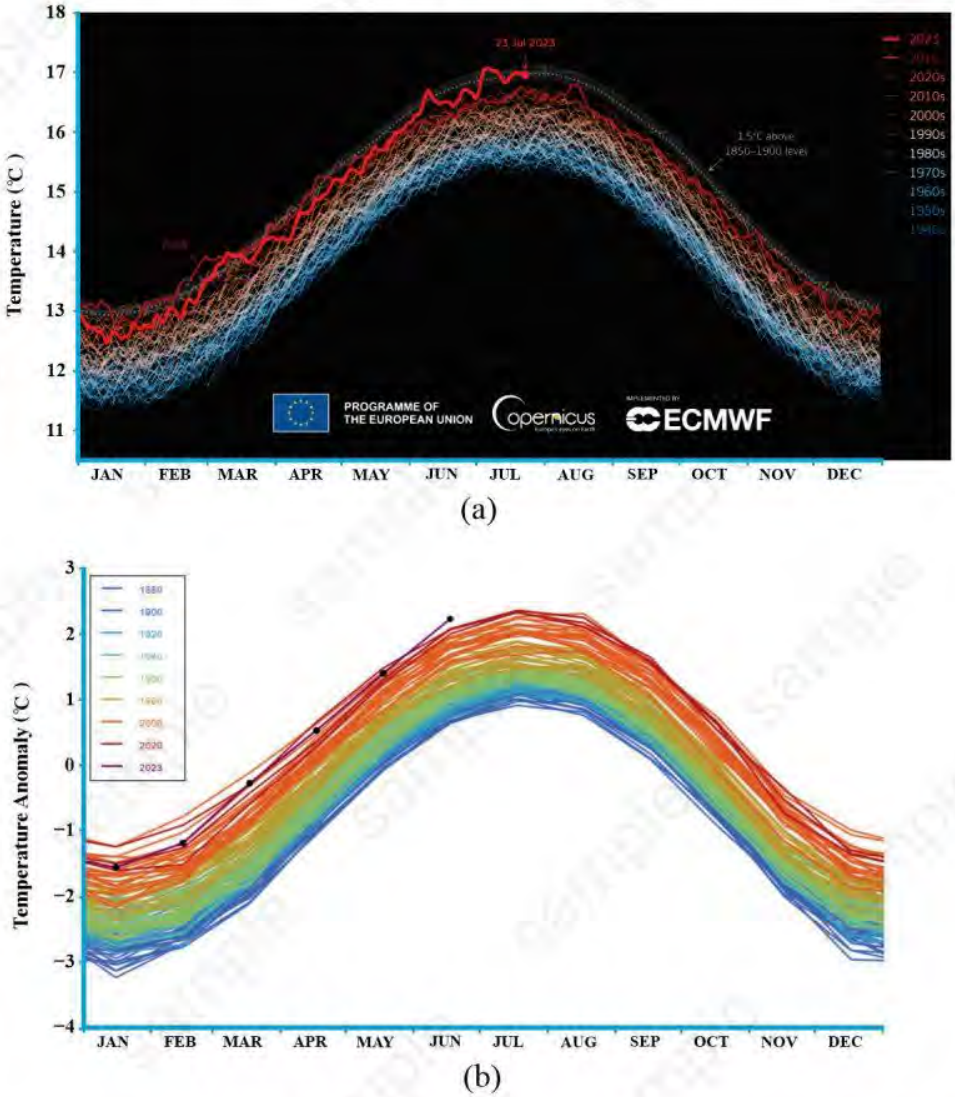

Figure 1. (**a**) Global daily surface air temperature from 1 January 1940 to 23 July 2023, displayed as a time series for each year and (**b**) temperature anomalies during the period 1980–2015 [26,27].

Temperature anomalies refer to the difference between the observed temperature and a reference temperature. In the context of climate science and global warming analysis, they are typically used to measure how much the Earth's surface temperature deviates from a specific baseline or average temperature. The baseline is often chosen as a reference period, such as pre-industrial times or a recent historical period with stable climate conditions. For example, the pre-industrial baseline could be the average temperature during the

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Article

On Variable Reverse Power Flow-Part I: Active-Reactive Optimal Power Flow with Reactive Power of Wind Stations

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Abstract: It has recently been shown that using battery storage systems (BSSs) to provide reactive power provision in a medium-voltage (MV) active distribution network (ADN) with embedded wind stations (WSs) can lead to a huge amount of reverse power to an upstream transmission network (TN). However, unity power factors (PFs) of WSs were assumed in those studies to analyze the potential of BSSs. Therefore, in this paper (Part-I), we aim to further explore the pure reactive power potential of WSs (*i.e.*, without BSSs) by investigating the issue of variable reverse power flow under different limits on PFs in an electricity market model. The main contributions of this work are summarized as follows: (1) Introducing the reactive power capability of WSs in the optimization model of the active-reactive optimal power flow (A-R-OPF) and highlighting the benefits/impacts under different limits on PFs. (2) Investigating the impacts of different agreements for variable reverse power flow on the operation of an ADN under different demand scenarios. (3) Derivation of the function of reactive energy losses in the grid with an equivalent-π circuit and comparing its value with active energy losses. (4) Balancing the energy curtailment of wind generation, active-reactive energy losses in the grid and active-reactive energy import-export by a meter-based method. In Part-II, the potential of the developed model is studied through analyzing an electricity market model and a 41-bus network with different locations of WSs.

Keywords: active-reactive energy losses; variable reverse power flow; varying power factors (PFs); wind power

1. Introduction

Buy-back is well-known in electricity markets where utilities or customers are buying or selling electric energy in a designed energy marketplace [1]. However, this issue becomes more complex if renewable energies and/or storage systems are considered in connected power systems with bidirectional active and reactive power flows as seen in Figure 1 [2].

Besides the literature review given in [2], we mention some other recent studies apparent in the area of reactive power of renewable energies for power market clearing. It is to note that new researches have been recently focused on optimal reactive power flow in transmission or distribution systems or in between based on a more detailed model. In [3], e.g., the authors proposed an algorithm to minimize reactive power provision, transmission loss costs and transmission system voltage security margin by a four-stage multi-objective mathematical programming method to settle the reactive power market. The authors in [3] focused later in [4] on the stochastic reactive power market in the presence of volatility of wind power generation in a transmission system. This kind of stochastic reactive power from wind generators was also studied in [5] for a medium-voltage (MV) network. The works in [4,5]

used a model for reactive power production from wind turbines based on a detailed induction machine equivalent circuit as presented in [6]. Other researchers [7], however, used a different model based on an electrical model of a wind turbine with a full scale converter. We note that reactive power contribution can also be modeled differently form photovoltaic [8] or energy storage systems [2]. From another point of view, not only active and reactive powers from renewable energies are important but also the modeling of demand in hybrid electricity markets [9,10]. Since considering "at once" all aspects and concerns in the power system shown in Figure 1 is prohibitive, our focus in this work will be on the power sub-system depicted in Figure 2.

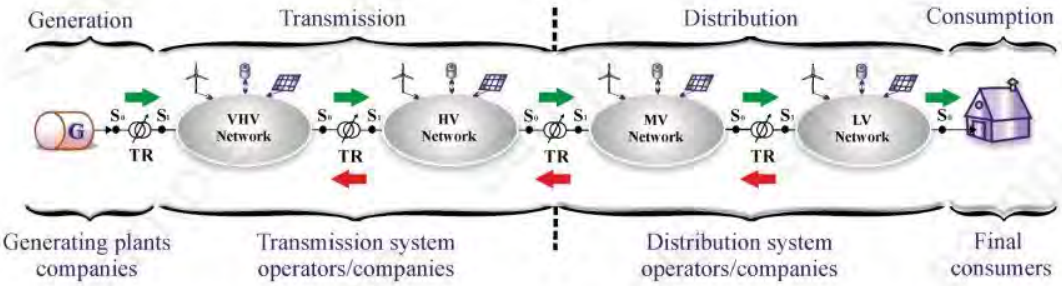

Figure 1. Conceptual structure of a future power system [2]. Here, S_0 stands for the primary side while S_1 for the secondary side of a transformer (TR) which is located between two different voltage levels.

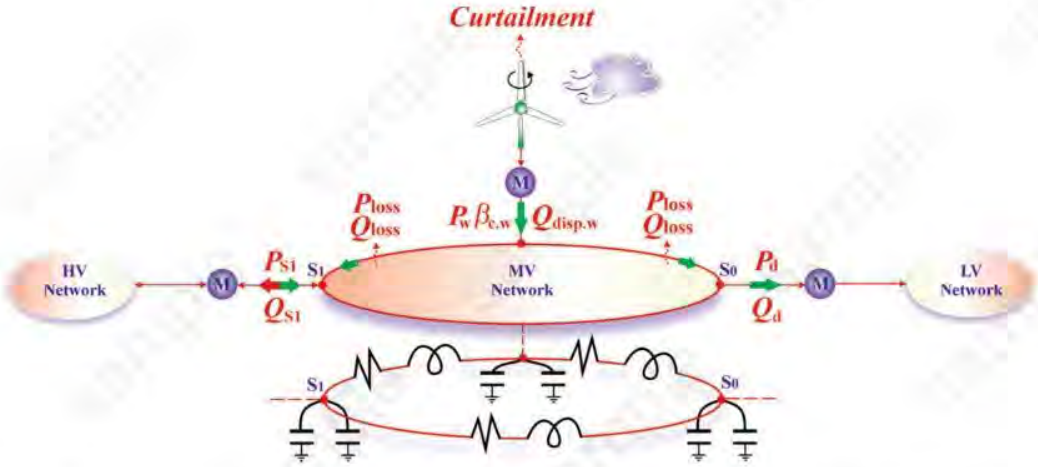

Figure 2. Illustration of the power system under consideration with a meter method [2]. In this paper, the low-voltage (LV) network is considered with unidirectional power flows while the high-voltage (HV) network with bidirectional power flows.

As shown in Figure 2, at the high-voltage transmission network (HV-TN), firm [11] and non-firm [12] wind energy penetration can be maximized. It was mentioned in [13] that unit commitment issues and the stability of voltage at a HV-TN have high effects on wind energy losses. Based on [11–13], other important factors which influence wind energy losses in a HV-TN were studied in [14]. It was shown that the reverse active power flow from a downstream medium-voltage active distribution network (MV-ADN) could be rejected at the HV-TN level. Based on the initial analysis in [14], it was assumed in [15] and [16] that all rates of flows for active and reactive power to the HV-TN could be accepted. However, in [15,16] wind stations (WSs) were assumed to operate with unity power factors (PFs) (*i.e.*, $Q_{\text{disp.w}} = 0$, see Figure 2) either for simplicity or to show the pure impacts of battery storage systems (BSSs).

Renewable energy curtailment and reverse power flow can also occur in a low-voltage ADN (LV-ADN) with a high renewable penetration from distributed generation (DG) units such as

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